EE-434 Power Electronics

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January 21, 2019

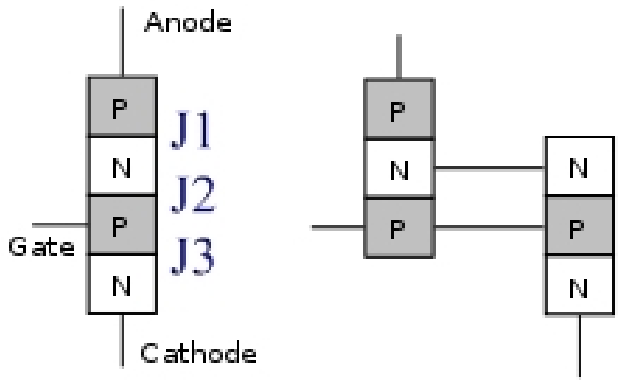
Overview

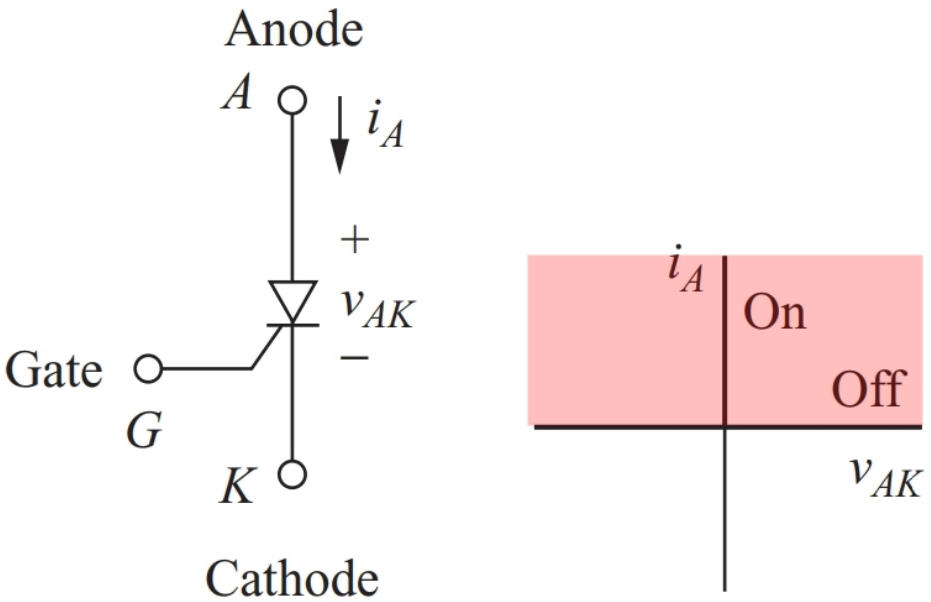
1. Electronic switches
   - Silicon controlled rectifier(SCR)
   - TRIAC
   - Gate Turn Off thyristor(GTO)

Silicon controlled rectifier(SCR) or thyristor

- It is a semi-controlled switch with 2 quadrant operation. It allows flow of current in positive direction and blocks the positive and negative voltage.
- Three terminal (Anode, cathode and gate) four layer device(PNPN).Gate is connected to second P.
- Turn on by applying a positive gate pulse wrt to cathode. No control for turn off.
- In this category SCR, GTO, MCT and triac are included. Generally thyristor is referred as SCR.
- Can handle large voltage and currents at reasonable frequency.
- Anode is usually mounted onto a heat sink or threaded to permit direct mounting onto an external heat-sink

Silicon controlled rectifier(SCR) or thyristor





Silicon controlled rectifier(SCR) or thyristor

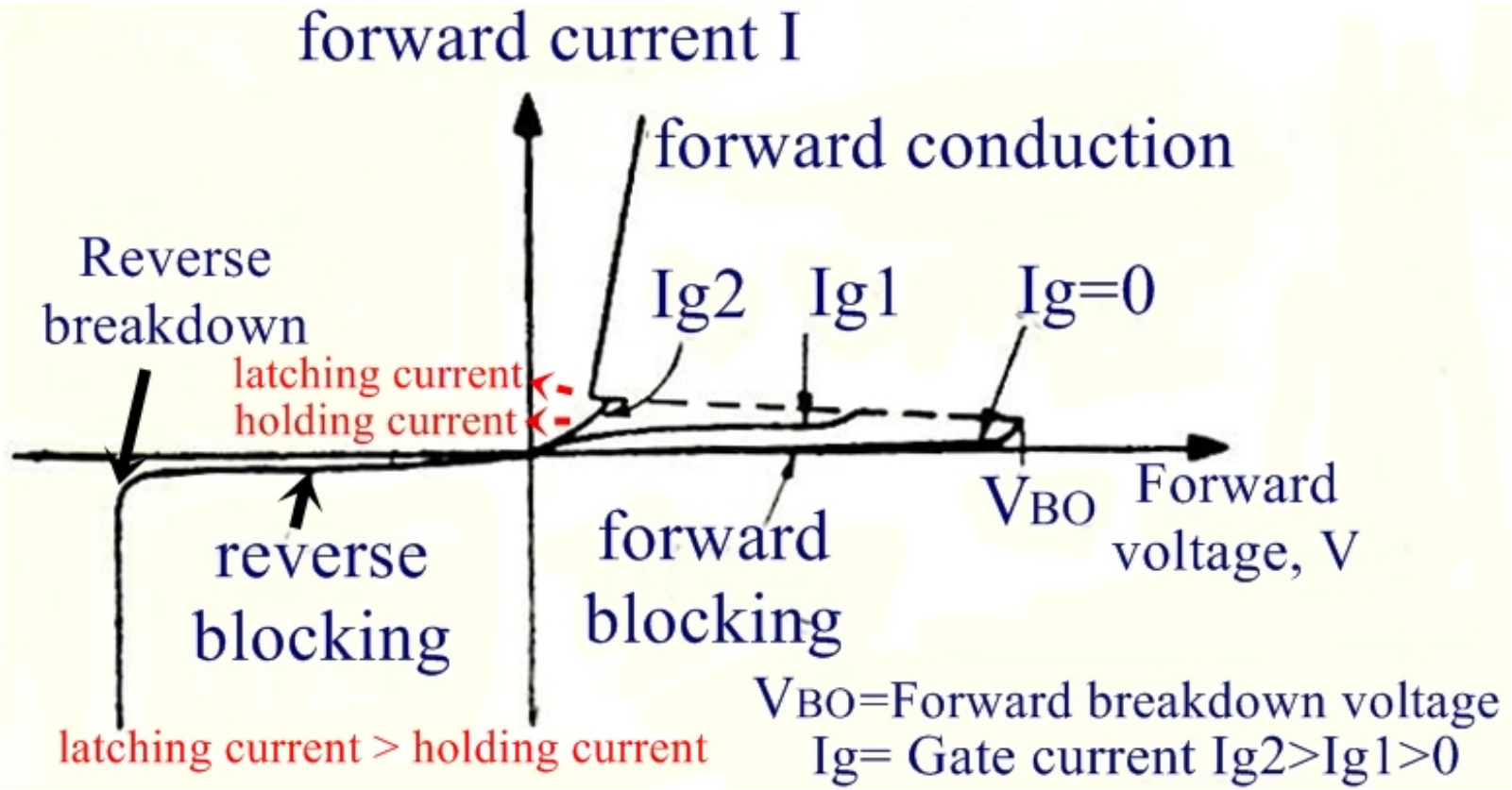


Figure: Static I-V charecteristics of Thyristor

SCR modes of operation

It has three modes of operation

- Reverse blocking
- Forward blocking
- Forward conduction

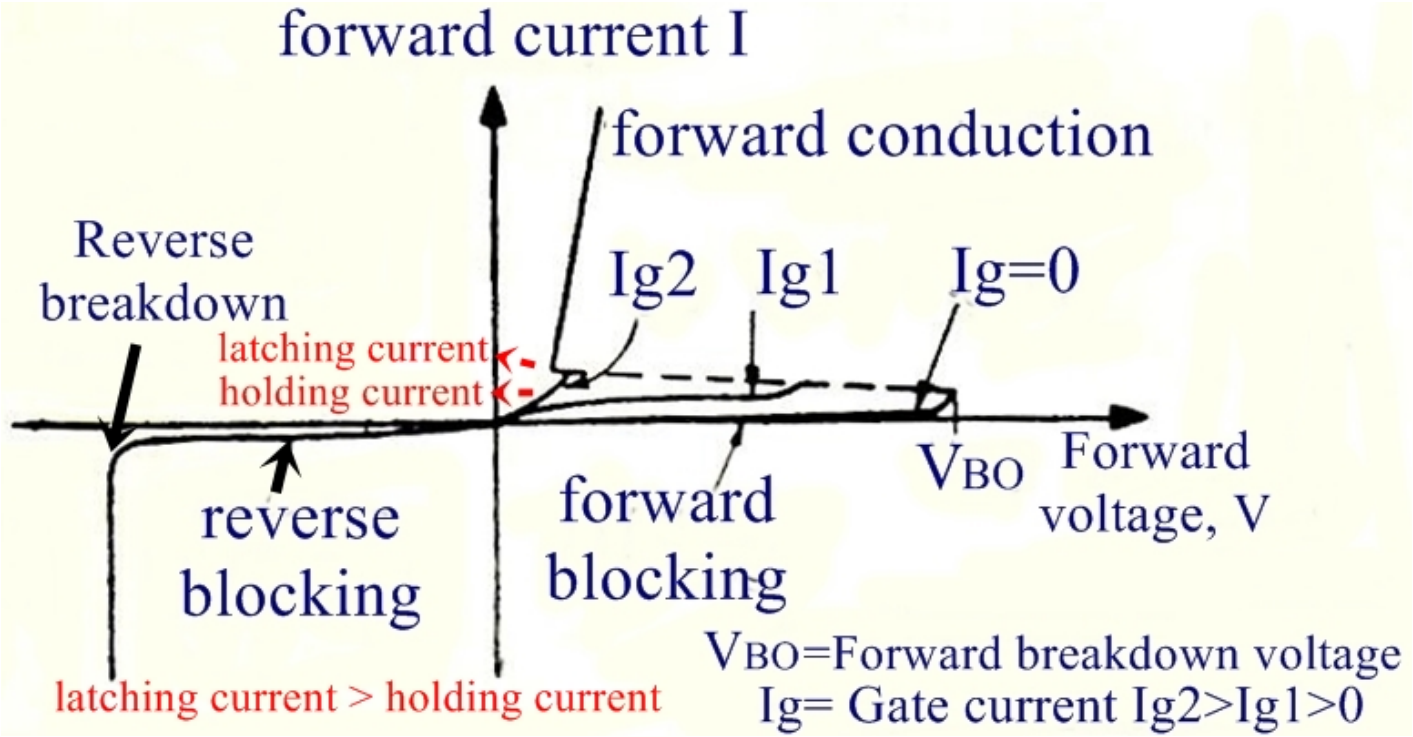
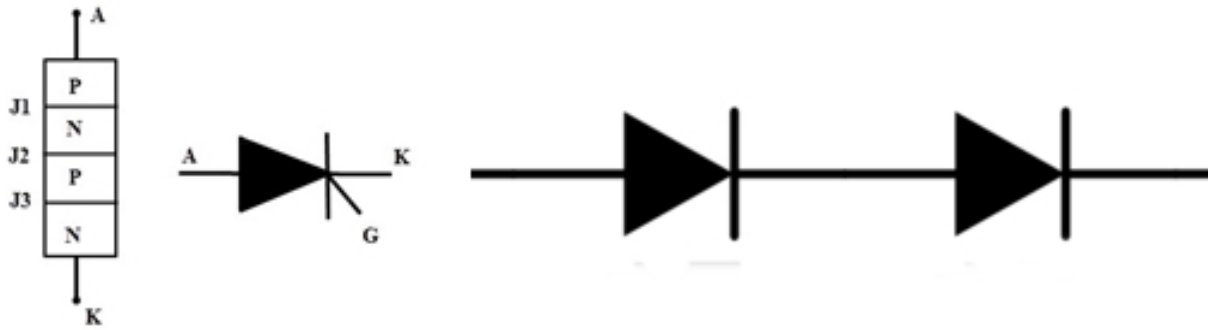


Figure: Static I-V characteristics of thyristor

SCR modes of operation — Reverse Blocking

Cathode is made positive with respect to anode ($V_{AK} < 0$).
Junction J_1 and J_3 are reverse biased. J_1 should block the entire voltage because N_2 is very thin and is highly doped.
Junction J_2 is forward biased.
This is similar like tow diodes connected in series and reverse voltage is applied.



A small leakage current flows only until the breakdown region is reached.
At the breakdown, large current flows with high voltage thus gives rise to large dissipation that can exceed the permissible junction temperature value.

SCR modes of operation — Reverse Blocking

Caution

Do not apply a gate pulse when a thyristor is in reverse blocking state

SCR is designed such that in reverse blocking state most of the reverse voltage drops across J_1.
If a positive gate signal is applied, then J_3 also becomes forward biased.
Remember J_2 is already forward biased and therefore, it injects holes into junction J_1.
This increases the reverse leakage current which, increases the junction heating that further increases the reverse current. This can lead to thermal runaway of the SCR.

SCR modes of operation — Forward Blocking and conduction

Anode is made positive with respect to cathode ($V_{AK} > 0$).
Junction J_1 and J_3 are forward biased.
Junction J_2 is reverse biased so entire V_{AK} appears across J_2.
J_2 limits forward current to the value of forward leakage current (several mA).

With forward biased voltage, SCR can be conducted using any techniques listed below.

- Exceeding the forward breakover voltage V_{BO}
- Gate triggering
- dv/dt turn on
- Irradiation of gate-cathode junction

Forward Conduction— Exceeding V_{BO}

If gate current is zero and applied voltage(V_{AK}) exceeds further than V_{BO}, then J_2 experiences avalanche breakdown. Hence, V_{BO} is called forward breakover voltage.
The characteristic curve (6) shift from a high voltage low current region to low voltage high current region.
In this case the current is controlled only by the external impedance of the circuit.
Forward voltage drop is usually between 1-1.5V.
Note that the current path is shown in dotted line pattern. It is because, with the decrease in voltage current increases i.e., it is acting like a negative resistance and therefore it is an unstable region.
If the anode voltage is reduced then the thyristor will continue to stay on because of the absence of J_2.
Thyristor will only turn off if the forward current drops below a certain value. The value of that current is called **holding** current or sustaining current.

Forward Conduction— Gate triggering

This is the most common method of firing a thyristor.
A suitable positive positive voltage is applied at gate to cathode terminals.
A layer at the gate is flooded by electrons from the cathode and it looses its identity as a layer.
Looking onto Fig.6, as the gate current increases, the voltage at which the device turn on also decreases. This is because the gate current reduces the depletion layer around J_2.
Thyristor is equivalent as a conducting diode in this state.
For a given forward voltage there is a minimum gate current at which a thyristor turns on. Usually it is between few milliamperes to several milliamperes.
Once a thyristor is turned on, gate current is no longer required therefore, a pulse is usually applied on the gate.

Forward Conduction— Gate triggering

If the gate pulse is removed before the forward current reaches a value called **latching current**, the thyristor will turn off again.
Gate pulse should be wide enough so that current exceeds latching current.
After this the gate has no control on the SCR. Latching current is higher than the holding current.
It is usually three times the holding current if not specified in the data sheet.

Forward Conduction— dv/dt turn on

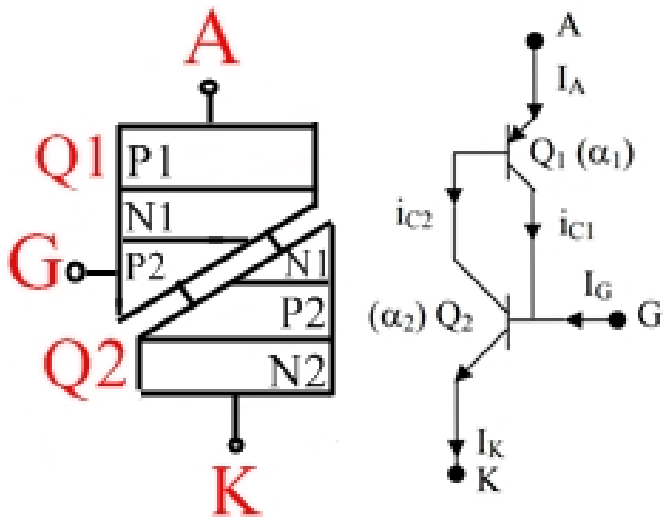
A thyristor can be turned off by a rapid rate of increase of forward anode to cathode voltage in the absence or presence of gate signal.
A rapidly rising anode voltage produces transient gate current due to junction capacitances. This current may be sufficient to turn on a thyristor.
This type is usually not used.
Such transients may occur because of other associated equipment as well, therefore it is ensured that the dv/dt across the thyristor s less the value at which it is turned on.
Typical dv/dt rating to avoid unwanted turn on are in range of 10-200v/ms.
The value of dv/dt can be increased by using low resistor.

Forward Conduction— Irradiation of Gate cathode junction

A thyristor can be turned on by a beam of light directed at the gate to cathode junction.
Mostly used in HVDC systems.

SCR — Two transistor analogy

An SCR can be dissected into a form where it resembles like an NPN and PNP transistor as shown below.



We know that

$$I_C = \alpha I_E + I_{CBO} \tag{1}$$

where, I_{CBO} is the leakage current of CBJ of Q_1 and $I_E = I_A$

SCR — Two transistor analogy

For Q_1, $I_E = I_A$

$$I_{C1} = \alpha_1 I_A + I_{CBO1} \tag{2}$$

For Q_2,$I_E = I_K$,

$$I_{C2} = \alpha_2 I_K + I_{CBO2} \tag{3}$$

Now, $I_E = I_C + I_B$, also, $I_{B1} = I_{C2}$, therefore adding (7) and (3)

$$I_A = I_{C1} + I_{C2} = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \tag{4}$$

For the bottom transistor, $I_K = I_{B2} + I_{C2}$. Now for some finite gate current I_G,

$$I_{B2} = I_G + I_{C1} \tag{5}$$

$$I_K = I_{C1} + I_G + I_{C2} = I_A + I_G \tag{6}$$

SCR — Two transistor analogy

Substituting (6) in (4),

$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)} \tag{7}$$

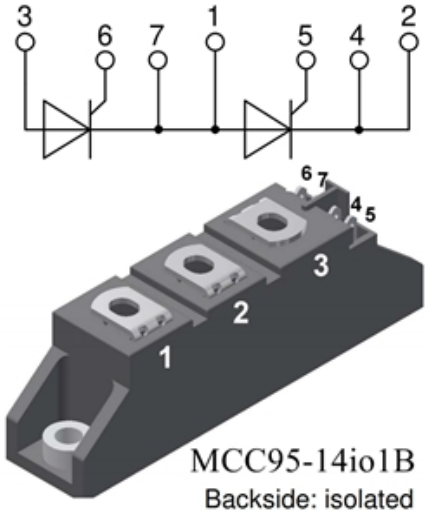
This presents, anode current as a function of gate current, leakage current and common mode current gain.

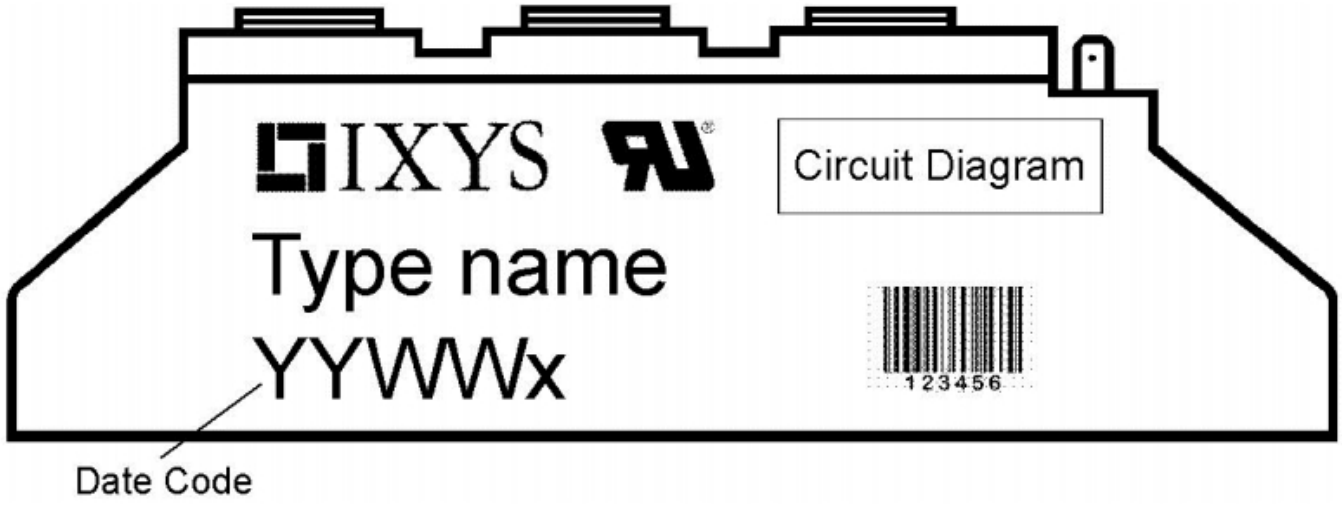
The thyristor datasheet

Important parameters in choosing an SCR are

- Average forward current
- Reverse blcoking voltage
- Off state current
- dv/dt and di/dt during turn on and off for snubber design
- Device turn off time to check the frequency

The thyristor datasheet MCC95-14io1B





The thyristor datasheet MCC95-14io1B

Thyristor				Ratings			
Symbol	Definition	Conditions		min.	typ.	max.	Unit
$V_{RSM/DSM}$	*max. non-repetitive reverse/forward blocking voltage*		T_{VJ} = 25°C			1500	V
$V_{RRM/DRM}$	*max. repetitive reverse/forward blocking voltage*		T_{VJ} = 25°C			1400	V
$I_{R/D}$	*reverse current, drain current*	$V_{R/D}$ = 1400 V	T_{VJ} = 25°C			200	µA
	Leakage current	$V_{R/D}$ = 1400 V	T_{VJ} = 125°C			5	mA
V_T	*forward voltage drop*	I_T = 150 A	T_{VJ} = 25°C			1.29	V
	Useful for ON state losses	I_T = 300 A				1.50	V
		I_T = 150 A	T_{VJ} = 125°C			1.28	V
		I_T = 300 A				1.70	V
I_{TAV}	*average forward current*	T_C = 85°C	T_{VJ} = 125°C			116	A
$I_{T(RMS)}$	*RMS forward current*	180° sine				182	A
V_{T0}	*threshold voltage* } *for power loss calculation only*		T_{VJ} = 125°C			0.85	V
r_T	*slope resistance* }					2.4	mΩ
R_{thJC}	*thermal resistance junction to case*					0.22	K/W
R_{thCH}	*thermal resistance case to heatsink*				0.20		K/W
P_{tot}	*total power dissipation*		T_C = 25°C			455	W
I_{TSM}	*max. forward surge current*	t = 10 ms; (50 Hz), sine	T_{VJ} = 45°C			2.25	kA
		t = 8,3 ms; (60 Hz), sine	V_R = 0 V			2.43	kA
		t = 10 ms; (50 Hz), sine	T_{VJ} = 125°C			1.92	kA
		t = 8,3 ms; (60 Hz), sine	V_R = 0 V			2.07	kA

The thyristor datasheet MCC95-14io1B

I^2t	*value for fusing*	t = 10 ms; (50 Hz), sine	T_{VJ} = 45°C			25.3	kA²s
		t = 8,3 ms; (60 Hz), sine	V_R = 0 V			24.6	kA²s
		t = 10 ms; (50 Hz), sine	T_{VJ} = 125°C			18.3	kA²s
		t = 8,3 ms; (60 Hz), sine	V_R = 0 V			17.7	kA²s
C_J	*junction capacitance*	V_R = 400 V f = 1 MHz	T_{VJ} = 25°C		119		pF
P_{GM}	*max. gate power dissipation*	t_P = 30 µs	T_C = 125°C			10	W
		t_P = 300 µs				5	W
P_{GAV}	*average gate power dissipation*					0.5	W
$(di/dt)_{cr}$	*critical rate of rise of current*	T_{VJ} = 125 °C; f = 50 Hz	repetitive, I_T = 250 A			150	A/µs
		t_P = 200 µs; di_G/dt = 0.45 A/µs;					
		I_G = 0.45 A; V = ⅔ V_{DRM}	non-repet., I_T = 116 A			500	A/µs
$(dv/dt)_{cr}$	*critical rate of rise of voltage*	V = ⅔ V_{DRM}	T_{VJ} = 125°C			1000	V/µs
		R_{GK} = ∞; method 1 (linear voltage rise)					
V_{GT}	*gate trigger voltage*	V_D = 6 V	T_{VJ} = 25°C			2.5	V
			T_{VJ} = -40°C			2.6	V
I_{GT}	*gate trigger current*	V_D = 6 V	T_{VJ} = 25°C			150	mA
			T_{VJ} = -40°C			200	mA
V_{GD}	*gate non-trigger voltage*	V_D = ⅔ V_{DRM}	T_{VJ} = 125°C			0.2	V
I_{GD}	*gate non-trigger current*					10	mA
I_L	*latching current*	t_p = 10 µs	T_{VJ} = 25°C			450	mA
		I_G = 0.45 A; di_G/dt = 0.45 A/µs					
I_H	*holding current*	V_D = 6 V R_{GK} = ∞	T_{VJ} = 25°C			200	mA
t_{gd}	*gate controlled delay time*	V_D = ½ V_{DRM}	T_{VJ} = 25°C			2	µs
		I_G = 0.45 A; di_G/dt = 0.45 A/µs					
t_q	*turn-off time*	V_R = 100 V; I_T = 150 A; V = ⅔ V_{DRM}	T_{VJ} = 100 °C		185		µs
		di/dt = 10 A/µs dv/dt = 20 V/µs t_p = 200 µs					

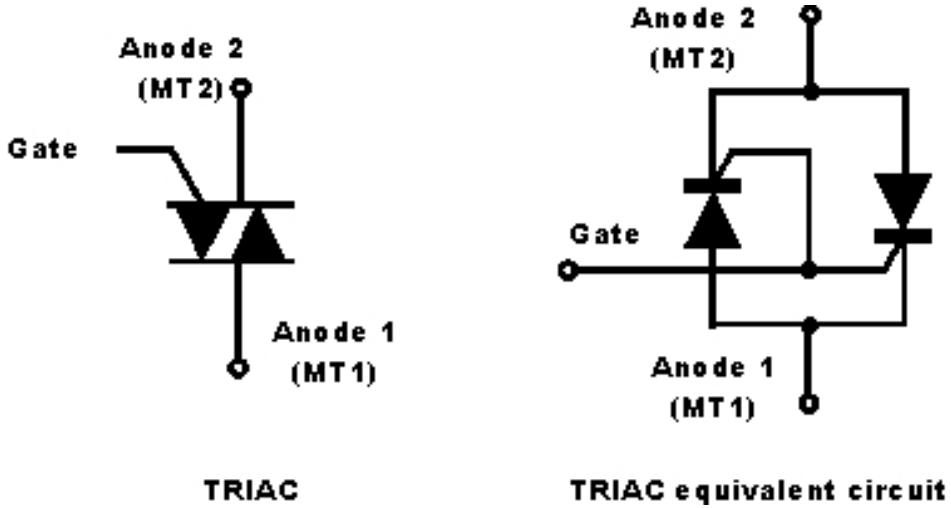
The thyristor datasheet

Important parameters in choosing an SCR are

- Average forward current
- Reverse blocking voltage
- Off state current
- dv/dt and di/dt during turn on and off for snubber design
- Device turn off time to check the frequency

TRIAC

For AC operation, a traditional SCR cannot be used.
One solution is to use two SCRs in anti-parallel connection.
This can also be done with a device called TRIAC (1964,GE).
It is a bidirectional device with a common gate.

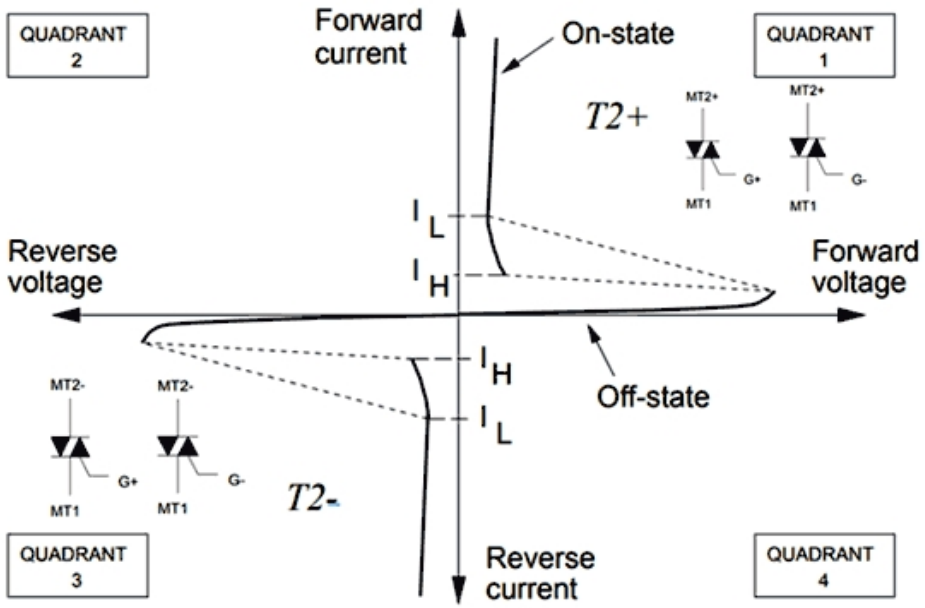


TRIAC | TRIAC equivalent circuit

Can be turned on by Making **MT2** $>$ **MT1** and applying **positive** gate current.
Making **MT1** $>$ **MT2** and applying **negative** gate current.

TRIAC

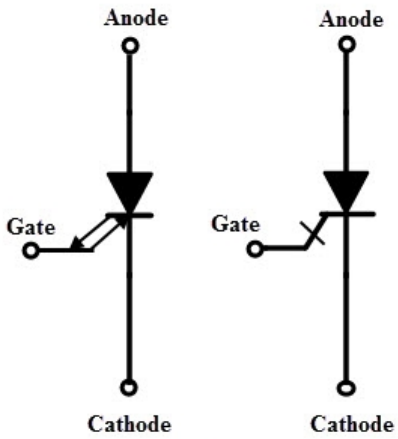
Figure shows the characteristics of a TRIAC.



Used in fan regulators.
TRIAC has less time to recover the blocking power compared to SCR. This means it has a tendency to misfire.

GTO

It can be turned off by negative gate current.
There is structural difference in terms of layer thickness and manipulation.
(More can be studied in the reference book)



Gate Turn-Off Thyristor Symbols